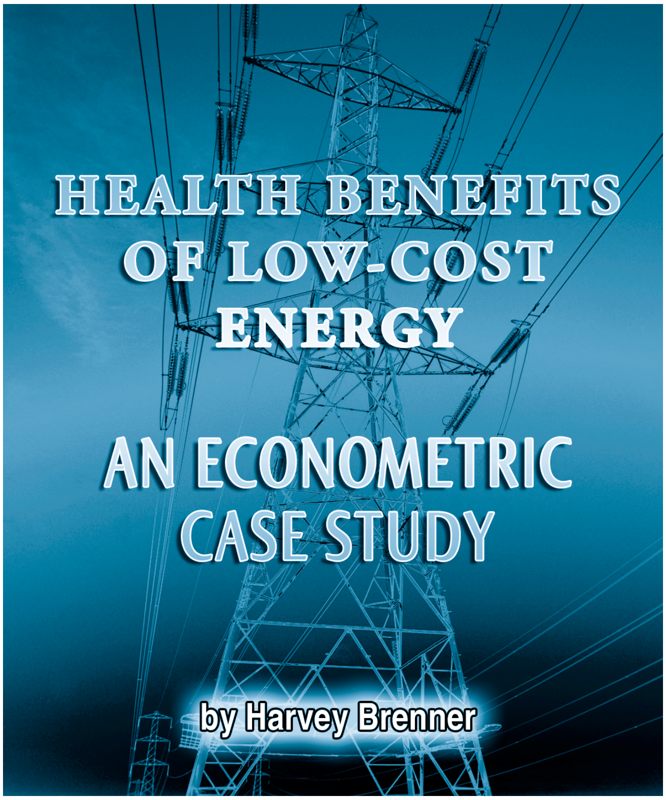

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Numerous studies conducted in the past 10–15 years have indicated that economic factors, such as income, employment, and socioeconomic status, affect disease and death.[1] The case study research described in this article shows how a large-scale econometric model—the application of statistical methods to the study of economic data and problems—can accurately predict long-term U.S. mortality trends based on variables such as per-capita income and unemployment rates (see Figure 1). In addition, it demonstrates that even short-term, year-to-year fluctuations in economic indicators can accurately predict year-to-year fluctuations in population mortality rates (see Figure 2). These results leave little doubt that the statistically significant relationships between socioeconomic indicators and population mortality rates identify principal risk factors to a population's health.

AN ECONOMETRIC MODEL

An econometric model was applied to a hypothetical regulatory case study, whereby U.S. coal was replaced by alternative higher-cost fuels such as natural gas for the purpose of electricity generation. The model was used to estimate the premature mortality associated with increased unemployment and reduced personal income. The adverse impacts on household income and unemployment due to the substitution of higher-cost energy sources were estimated to result in 195,000 additional premature deaths annually (see Table 1).

The results from this hypothetical case study may be scaled to apply to specific policy initiatives affecting the U.S. coal-based electricity generation sector. For example, the U.S. Department of Energy's Energy Information Administration (EIA) estimates that climate change bills currently before the U.S. Congress—such as Senate Amendment No. 2028, rejected by the Senate in 2003 and again in June 2005—could result in the displacement of up to 78% of U.S. coal-based electricity generation with higher-cost energy sources.[2] The methodology employed here suggests that, absent any direct mitigation measures to offset expected decreases in employment and income,[3] implementation of such measures could result in an annual increase of premature mortality rates by more than 150,000.

> Governmental programs intended to protect public health and the environment should take into account potential income and employment effects of required compliance measures.

These predicted mortality trends are an order of magnitude greater than recent estimates of the premature mortality benefits associated with implementation of the U.S. Environmental Protection Agency's 8-hr ozone standard (approximately 1000–3000 premature deaths avoided annually)[4] and fine particulate ($PM_{2.5}$) standard (approximately 15,000 premature deaths avoided annually).[5] In this context, a major implication of this research is that governmental programs intended to protect public health should take into account potential income and employment effects of required compliance measures. By increasing the costs of goods and services such as energy, and decreasing disposable incomes, regulation can inadvertently harm the socioeconomic status of individuals and, thereby, contribute to poor health and premature death.

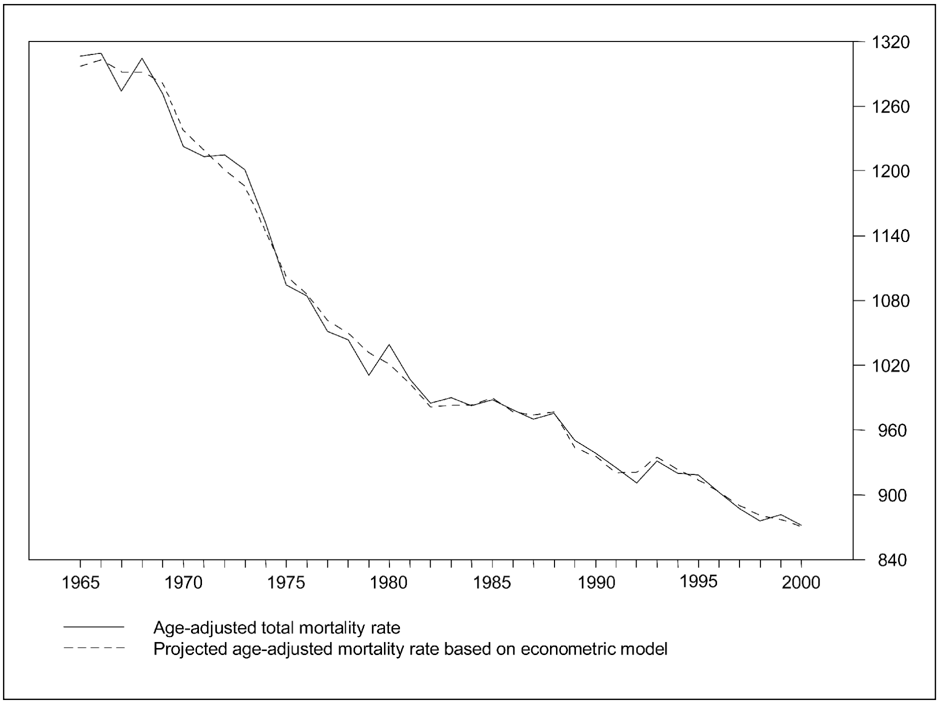

Figure 1. U.S. total mortality rate, real and projected, 1965–2000 (Level model; age-adjusted per 100,000 population).

manner. Assuming these estimates to be approximately correct, and given the epidemiological findings on socioeconomic status and health,[1,3,9-11] it follows that these proposed policies might, in effect, bring about a net increase in population mortality.

ENERGY AND HEALTH

Energy is among the most indispensable ingredients of human existence. Like most advanced industrial economies, the United States depends primarily on carbon-based (and carbon-emitting) energy. In 2003, U.S. energy users consumed a total of 98 quadrillion British Thermal Units (quads) of energy, including 39 quads of petroleum, 23 quads of natural gas, and 23 quads of coal. Nuclear, hydro, and other non-carbon-emitting energy sources supplied the remaining 14 quads, or 15% of total energy consumption.[6] Emissions from coal-based electricity generation plants alone represented one-third of U.S. carbon dioxide (CO_2) emissions in 2002.[7]

A substantial body of literature has developed examining the potential impacts of proposed restrictions on greenhouse gas emissions on the national gross domestic product (GDP), energy prices, income, and employment.[8] It has been estimated, for example, that global climate change initiatives requiring expanded use of high-cost, lower-carbon energy alternatives such as natural gas would increase the cost of energy to the point that per-capita income and employment rates would decrease in a quantitatively predictable manner.

LINKS BETWEEN HEALTH AND INCOME

The socioeconomic-status findings show that changes in the economic status of individuals produce subsequent changes in the health and life span of those individuals. Unfortunately, traditional epidemiological literature has not dealt with the issue of change in socioeconomic status in relation to changes in health status. However, another body of research shows that decreased real income per capita and increased unemployment have consequences that lead to increased mortality in U.S. and European populations.[3,9-11] This literature uses econometric analyses of time-series data to measure the relationship between changes in the economy and changes in health outcomes.

The econometric approach to health impact assessments was developed initially in two studies for the Joint Economic Committee (JEC) of the U.S. Congress in 1979[9] and 1984.[10]

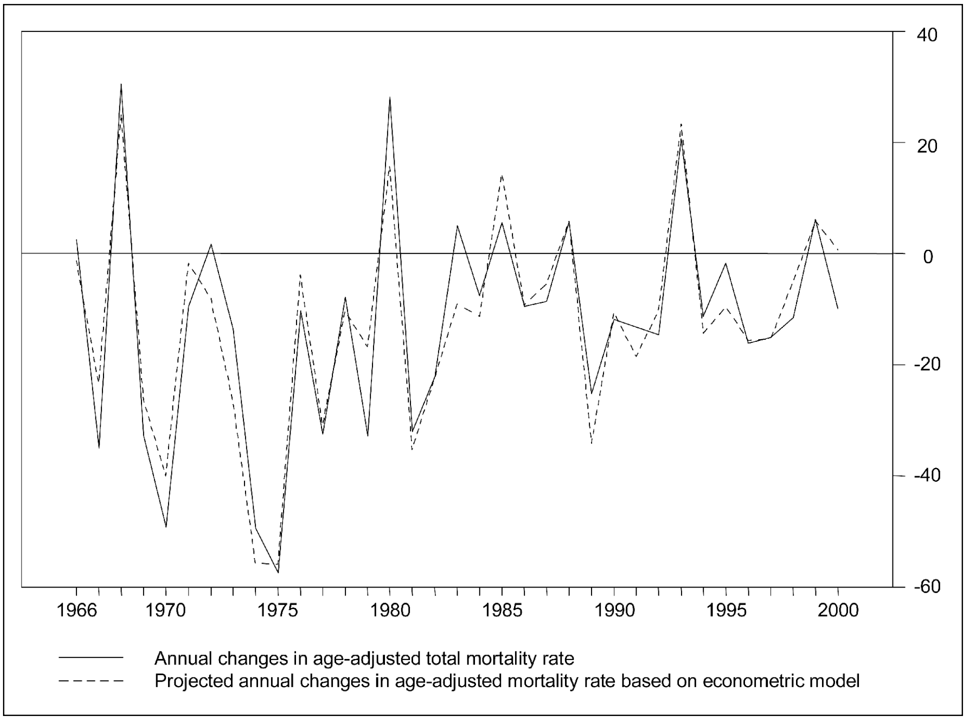

Figure 2. Annual changes of U.S. total mortality rate, real and projected, 1966–2000 (First difference model using error correction method [ECM]; age-adjusted per 100,000 population).

Table 1. Estimates of premature mortality impacts in 2010 of hypothesized elimination of coal utilization for electricity generation.

Year	U.S. Population	Annual Growth
2000	282,125,000	
2010	310,013,000	0.95%

Model Types		Base (2010)	Mortality Rates[a] Final	Delta	Base	Final	Number of Deaths Low SD (95% confidence)[b]	Delta	High SD (95% confidence)[b]	Delta Growth (%)[c]
Model 1 – Unemployment Rate (UR)	Level model	797	852	55	2,470,804	2,641,311	166,505	170,507	174,510	6.9
	First difference model	811	870	59	2,514,205	2,697,113	178,282	182,908	187,533	7.3
Model 2 – Employment Rate (ER)	Level model	885	947	62	2,743,615	2,935,823	188,555	192,208	195,861	7
	First difference model	915	976	61	2,836,619	3,025,727	185,620	189,108	192,596	6.7
Model 3 – GDP per capita (GDPP)	Level model	1392	1,504	112	4,315,381	4,662,596	342,597	347,215	351,832	8
	First difference model	1463	1,582	119	4,535,490	4,904,406	364,252	368,915	373,579	8.1
Model 4 – Model # 3 level with Model #2 first difference	First difference model	1406	1469	63	4,358,783	4,554,091	193,181	195,308	197,435	4.5
Average		**1096**	**1171**	**76**	**3,396,414**	**3,631,581**	**231,285**	**235,167**	**239,049**	**6.9**

Model Type	Mortality Rate	Weights[d]	Number of Deaths
Model 4	**Delta**		
First difference model	195,308		
UR		0.246	48,079
ER		0.266	52,037
GDPP		0.487	95,192
Total		**1.000**	**195,308**

[a]Base = 2010 forecast; Final = 2010 forecast with coal utilization impact. The impact on UR is the average of the DRI[14] and Rose and Yang[15] estimates for job loss % change from the 4% assumed 2010 base level. The impact on ER is assumed to be a minus 2% change from the 2010 base level. The impact on GDPP is the average of the DRI[14] and Rose and Yang[15] estimates for personal income % change the 2010 base level; Delta = 2010 forecast, no population assumption needed. [b]Error forecast standard deviation (SD). [c]Delta mortality rate divided by the 2010 base forecast. [d]Weights calculation = Step 1: GDPP weight is estimated as 1 minus Delta from Model 2 first difference divided by Delta from Model 3 first difference; Step 2: UR weight is estimated as 1 minus GDPP weight divided by 2 multiplied by Delta from Model 1 first difference divided by Delta from Model 2 first difference; Step 3: ER weight is estimated as 1 minus GDPP weight minus UR weight; by definition weights sum to 1.

These studies demonstrated that declines in real income per capita and increases in unemployment led to elevated mortality rates over a subsequent period of six years. For example, the 1984 JEC study found that a one-percentage-point increase in the unemployment rate (e.g., from 5% to 6%) would lead to a 2% increase in the age-adjusted mortality rate. The growth of real income per capita also showed a significant correlation to decreases in mortality rates (except for suicide and homicide), mental hospitalization, and property crimes. Over the past four years, the European Commission has supported similar research showing comparable results throughout the European Union.[11]

UPDATED MODEL RESULTS

The research described in this article updates the 1984 JEC analysis. U.S. data for the period 1965–2000 were employed to estimate mortality rates and other health effects of changes in economic conditions. The econometric model combined four predictive factors in the explanation of U.S. mortality trends and fluctuations:

1. real GDP per capita (beneficial impact on mortality);
2. employment ratio (beneficial impact);
3. unemployment rate (harmful impact); and
4. the interaction between GDP and unemployment as coincident and lagging business-cycle indicators (harmful impact).

At the national level, the findings confirmed that the hypothesized benefits of real income per capita and employment were strong and statistically significant, while the damaging effects of increased unemployment and acute business-cycle disturbances were similarly robust and statistically significant. Figure 1 demonstrates the model's projection of U.S. mortality rates.

As in the 1984 JEC study, the upward trends in real income per capita represented the most important factor in decreased U.S. mortality rates since the 1960s. Also, the unemployment rate continued to bear a significant correlation to increased mortality rates, such that an increase of 1% in the unemployment rate eventuates in an approximately 2% increase in the age-adjusted mortality rate, estimated cumulatively over at least the subsequent decade.

In sum, growth in real income per capita is the backbone of decreases in the U.S. mortality rate.

In sum, growth in real income per capita is the backbone of decreases in the U.S. mortality rate. There are several reasons for this. First, with respect to physical health, economic growth is fundamental in meeting basic population needs, such as nutrition, housing, health insurance,[12] medical care, sanitation, electricity, transportation, and climate control. In addition, economic growth enables increased industrial investment in pollution control technologies and safer work environments, with minimal adverse workplace exposures to chemicals, noise, and unsanitary conditions.

Year-to-year fluctuations in mortality rates are largely explained by annual changes in the behavior of variables in the model (see Figure 2). This means that a decline in the mortality rate from one year to the next (e.g., between 1981 and 1982) is related to increased real income per capita and declining unemployment rates during that same year's change (1981–1982) and the (approximately) 10 years prior to that same year's mortality decline.

State and Regional Analyses

If the economic model explaining mortality changes in the overall United States applied to all of its regions, or to a large number of states, then it would necessarily follow that the historical pattern of mortality rate changes in the regions and states would resemble one another. If true, this would be remarkable, in that there is no existing literature indicating that the trends and fluctuations in mortality rates are similar among the major regions of the United States.

Regional and state modeling to test the robustness of the national model constituted a major effort of the present analysis.

The U.S. national-level model was applied to the explanation of mortality rate changes in five populous and geographically diverse states: California, Texas, New York, Florida, and Illinois. The results were remarkably similar in that the overall U.S. model applied quite precisely to each of those five states. The model's principal predictive variables all showed statistically robust relations to the age-adjusted mortality rate. It should be pointed out that the coefficients, representing the extent of change in mortality related to changes in the economic variables, were not identical from state to state. Nevertheless, it is important to note that the same economic model described historical changes in mortality rates of states thousands of miles from one another, with vastly different economies, patterns of urbanization, and a host of lifestyle, social, and environmental factors. Similar findings resulted from application of the model to regional data for the United States.

All statistical tests traditionally used in time-series analysis, as well as the forecasting capacity of the model, demonstrate that each of the variables in the model plays a highly significant role and that the entire model is of great statistical significance. The overall results, prevalent throughout the United States, demonstrate (1) long-term declining mortality rates related to patterns of economic growth, and (2) short-term fluctuations in mortality rates associated with recessions, structural unemployment rates, and the lag of unemployment rates behind changes in real GDP per capita (a standard feature of the business cycle).

CASE STUDY: MORTALITY EFFECTS OF ENERGY SUPPLY CHANGES

The national econometric model was applied to a case study to quantify the increased mortality rate that could result from potential decreased real income per capita and increased unemployment rates due to regulatory constraints on U.S. coal utilization. Numerous policy proposals to reduce greenhouse gas emissions have called for restrictions of carbon emissions by the U.S. electricity-generating sector. [13]

Under the hypothetical scenario that coal production and related electricity generation were eliminated in favor of lower-carbon, higher-cost alternatives such as natural gas combined-cycle generation, an additional 195,000 premature deaths were estimated to occur by the year 2010 (see Table 1). This is a conservative estimate based on a tight construction of the assumptions of the future behavior of the study variables (e.g., real income per capita, unemployment rates) to 2010.

The case study used inputs from two analyses of the impacts of reduced coal utilization on U.S. income and employment data, each offering disaggregated state-level estimates of income and employment effects. Standard & Poor's DRI (1998)[14] and Rose and Yang of The Pennsylvania State University (2001)[15] used alternative macroeconomic and input–output models, respectively, to estimate the reductions of income and employment associated with large-scale displacement of coal use. The findings from these studies were scaled to approximate the effects of a hypothetical 100% replacement of coal. Thus adjusted, the estimated increased unemployment in 2010 ranged from 3.2 million (Rose and Yang) to 4.6 million jobs (DRI). The reduction in household income was estimated in a range of $166 billion (Rose and Yang, 1999$) to $363 billion (DRI, 1992$).

This upward scaling provided the basis for an assessment of policy proposals that could result in specific energy supply changes. For example, in a recent study, EIA estimates that the climate change proposals currently before the U.S. Congress could lead to the displacement of 59–78% of U.S. coal-based electricity generation by higher-cost natural gas and other alternative generation sources.[2]

The results from this hypothetical case study demonstrate that increased mortality rates would result from decreased household income and increased unemployment associated with a shift to higher cost energy supply options, absent any direct mitigation programs that effectively prevented or offset these effects. The estimated increased mortality in the year 2010, based on four different variations of the econometric model, ranges from an additional 170,507 to 368,915 deaths for the displacement of 100% of coal-based generation. A moderately conservative estimate based on an annual change model would be an additional 195,308 deaths. This point estimate has a 95% confidence interval of 193,181–197,435 individual deaths.

Given an estimated potential displacement of 78% of U.S. coal generation based on EIA's study of proposed climate

REFERENCES

1. See Wildavsky, A. *Searching for Safety*; Transaction Books (Rutgers University): New Brunswick, NJ, 1988; Keeney, R. Mortality Risks Induced by Economic Expenditures; *Risk Analysis* **1990**, *10* (1); 147-59; Adler, N. Ostrove, J. Socioeconomic Status and Health: What We Know and What We Don't; *Ann. NY Acad. Sci.* **1999**, *896*; 3-15.
2. *Analysis of Senate Amendment, 2028*; U.S. Department of Energy's Energy Information Administration: Washington, DC, May 2004; Table 2.
3. See *Employment in Europe 2000, Recent Trends and Prospects*; European Commission Dir.-Gen. for Employment and Social Affairs, Unit A.1: Luxembourg, 2003; *Employment Policies in the EU and in the Member States—Joint Report, 2002*; European Commission Dir.-Gen. for Employment and Social Affairs, Unit A.1: Luxembourg, 2003; *Human Capital in a Global and Knowledge-Based Economy, Part II: Assessment at the EU Country Level*; European Commission Dir.-Gen. for Employment and Social Affairs, Unit A.1: Luxembourg, 2003.
4. Hubbell, B.; Hallberg, A.; McCubbin, D.; Post, E. Health-Related Benefits of Attaining the 8-Hr Ozone Standard; *Environ. Hlth. Perspect.* **2005**, *113*; 83-82.
5. *Regulatory Impact Analysis for the Particulate Matter and Ozone National Ambient Air Quality Standards and Proposed Regional Haze Rule*; ES-18; U.S. Environmental Protection Agency: Washington, DC, July 15, 1997.
6. *Short-Term Energy Outlook, 2004*; U.S. Department of Energy's Energy Information Administration: Washington, DC, 2004.
7. *Annual Energy Outlook, 2004*; U.S. Department of Energy's Energy Information Administration: Washington, DC, 2004.
8. See *Impacts of the Kyoto Protocol on U.S. Energy Markets and Economic Activity*; U.S. Department of Energy's Energy Information Administration: Washington, DC, 1998; The High Costs of the Kyoto Protocol; Wharton Econometric Forecasting Associates Inc.: Philadelphia, PA, 1998; Manne, A.; Richels, R. *Economic Impacts of Alternative Emission Reduction Scenarios*; American Council for Capital Formation Center for Policy Research: Washington, DC, 1998.
9. Brenner, M.H. *Estimating the Social Costs of National Economic Policy: Implications for Mental and Physical Health and Criminal Aggression*; Joint Economic Committee, U.S. Congress: Washington, DC, 1979.
10. Brenner, M.H. *Estimating the Effects of Economic Change on National Health and Social Well-Being*; Joint Economic Committee, U.S. Congress: Washington, DC, 1984.

change initiatives, the indicated premature mortality from reduced income and increased unemployment would exceed 150,000 deaths annually, absent any direct and effective mitigation programs.[3] The effects of other policy measures entailing significant, near-term disruption of energy supply markets could be estimated with a similar linear interpolation of these model results. However, the model does not reliably lend itself to estimation of mortality effects associated with relatively minor shifts in regional coal production or electricity generation (e.g., 10–15%). In many instances, such production shifts tend to be offsetting, as production decreases in one region are offset by gains elsewhere.

Effects of Lagged Relationships

The relationship between change in the economic circumstances of people's lives and their subsequent health status unfolds over time. In the case of sharp stress reactions to financial or employment catastrophes, the reaction patterns may be very rapid, that is, within a single year. This is clearly the case when suicide rates are factored in, as these rates typically rise sharply within several months of increases in national unemployment rates. Chronic diseases such as cardiovascular diseases, on the other hand, are known to respond to many different health risk factors within years, if not decades.

In addition to the potential health effects of income loss and unemployment, one has the problem of judging at what point to begin the estimation of the impact of increased unemployment. The difficulty here is that in classic analyses of business cycles, national income—specifically, GDP per capita—is a "coincident" business cycle indicator, meaning that changes in it tend to coincide with the timing of business cycles. Unemployment rates, on the other hand, are "lagging" business cycle indicators. This means that, despite even robust economic growth, during much of the initial year of recovery from a recession, unemployment rates may still remain high.

If one does not take into account these basic relationships between income and unemployment change on one hand and mortality on the other over at least a decade, it is possible to arrive at the misinterpretation that without lag there might be a negative relation between unemployment and mortality. This could imply that unemployment (in the very short term) is related to decreased mortality.[16] This type of error becomes more likely if one does not control for the usual impact of traditional risk factors on mortality, such as the effects of tobacco and saturated fat consumption on cardiovascular mortality rates over at least a decade.

In virtually all of the studies on unemployment and health, unemployment (especially long-term) is definitively associated with higher illness and mortality rates at the individual level of analysis.[17] But perhaps the most powerful evidence that economic growth is the fundamental source of life-span longevity improvement is that, as shown in the present study, the trends of decline in mortality rates across diverse states and regions of the United States are related to those in real GDP per capita cumulated for at least 10 years.

Influence of Other Health Factors

The model described here was evaluated to determine whether control for principal epidemiological risk factors to health would render the predictive variables insignificant. The result was that, while known risk factors to health, such as high consumption of tobacco, alcohol, and fatty foods, are additionally significant predictors of mortality, they are subordinate to the main economic predictors of the model that routinely influence mortality.

Since the late 1960s, increasing real income per capita in the United States is no longer positively related to consumption of tobacco, alcohol, and fatty foods. Indeed, after 1970, in the United States and much of Europe, these health risk factors ceased to be found more frequently in higher income segments of society and came to be linked instead to the lifestyles of lower socioeconomic groups. Thus, the population groups that generally have benefited least from economic growth and have been most vulnerable to problems of structural and cyclical losses of employment are most likely to suffer from the risks of dietary and addictive "lifestyle" health risks.

CONCLUSIONS

This study demonstrates the fundamental importance of sustained economic growth to health and improved life span for the U.S. population. The technological bases of long-term economic growth continue to involve the harnessing of energy supplies to enable humans to produce more per unit of labor or capital investment. The economic growth that continuously improves human life expectancy requires access to affordable energy. In this fundamental sense, any policy change that reduces growth or raises the level of unemployment should therefore be defined and addressed as a public health issue requiring an economic policy response that limits or offsets these results. The implication of the research described in this article provides an important basis for future studies of energy and health. **em**

11. See Brenner, M.H. *Estimating the Social Cost of Unemployment and Employment Policies in the European Union and the United States*; European Commission Dir.-Gen. for Employment, Industrial Relations, and Social Affairs: Luxembourg, 2000; Brenner, M.H. *Unemployment and Public Health in Countries of the European Union*; European Commission Dir.-Gen. for Employment, Industrial Relations, and Social Affairs: Luxembourg, 2003.
12. See McWilliams, J.M.; Zaslavsky, A.; Meara, E.; Ayanian, J. Health Insurance Coverage and Mortality Among the Near-Elderly; *Health Affairs* **2004**, *23* (4); 223.
13. For example, S.139 calls for a two-phase reduction of U.S. carbon dioxide emissions, achieving stabilization of emissions at 2000 levels by 2010, and a return to 1990 emission levels by 2020. The scaled-down version of this bill (S.A. 2028) rejected by the U.S. Senate in 2003 sought to achieve stabilization of carbon emissions at 2000 levels by 2010.
14. The Impact of Meeting the Kyoto Protocol on Energy Markets and the Economy, Standard & Poor's DRI, New York, 1998.
15. Rose, A.; Yang, B. The Economic Impact of Coal Utilization in the Continental United States, The Pennsylvania State University, University Park, PA, 2001.
16. Ruhm, C.J. *Healthy Living in Hard Times*; Working Paper No. 9468; National Bureau of Economic Research: Cambridge, MA, 2003.
17. See Bjorklund, A.; Eriksson, T. (1998) Unemployment and Mental Health: Evidence from Research; *Work and Stress*, **2000**, *13*; 204-222; Kokko, K.; Pulkkinen, L.; Puustinen, M. Selection into Long-Term Unemployment and Psychological Consequence; *Int. J. Behavioral Develop.* **2000**, *24*; 310-320; Novo, M. Unemployment and Mental Health in Galicia, Spain; *Int. Arch. Occ. & Environ. Hlth.* **1999**, *72*; s14-s15; Tausig, M.; Fenwick, R. Recession and Well-Being; *J. Health and Soc. Behavior* **1999**, *40*; 1-16.